

the thermal stability for the MR ratio.

First, regarding the viewpoint of the bias point, USP No. 5,422,591 has no disclosure of direct description or indirect suggestion. The constitution of the film (2) could not be used at all in practical heads. The reasons are mentioned in detail hereunder.

In the same manner as in Comparative Case 1, the current magnetic field,  $H_{cu}$ , is obtained on the basis of the experimental data of the specific resistance of each layer. In this case, the specific resistance of Ta is presumed to be  $100 \mu\Omega\text{cm}$ , and the experimental data of FeMn, NiFe, spacer Cu and subbing Cu are  $250 \mu\Omega\text{cm}$ ,  $20 \mu\Omega\text{cm}$ ,  $8 \mu\Omega\text{cm}$  and  $10 \mu\Omega\text{cm}$ , respectively. The sense current is 4 mA. Though not described in USP No. 5,422,591,  $H_{in}$  has been found to fall between 15 Oe and 25 Oe through our experiments. In this case,  $H_{in}$  is 20 Oe.

The bias point is calculated for high-density recording heads for which the size of the device is as follows: track width =  $0.5 \mu\text{m}$ , MR height = 0.3 to  $0.5 \mu\text{m}$ . The data are in Table 2.

Table 2

Calculated Bias Point in the Constitution of Comparative Case 2 in which the subbing Cu thickness is varied

MR height	Cu (0 nm)	Cu (1 nm)	Cu (2 nm)
$0.3 \mu\text{m}$	126 %	143 %	156 %

0.5 $\mu\text{m}$	111 %	127 %	140 %
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In this constitution, the pinned layer stray magnetic field from the pinned layer to the free layer is extremely large, and the bias point is readily shifted to the plus side. As is known from the data of the bias point in Table 2, in the samples with no spin filter effect in which the subbing Cu thickness is zero, the bias point falls between 111 % and 126 % at the MR height of from 0.3 to 0.5  $\mu\text{m}$ . This means that the samples produce no output. This situation gets worse when the subbing Cu layer thickness is thick as shown in table 2.

Fig. 12 is a conceptual view of the bias point versus  $H_{in}$ ,  $H_{pin}$  and  $H_{cu}$  on a transfer curve. As  $H_{pin}$  is large, the bias point oversteps the level when the current is zero. This constitution is so designed that the bias point is forcibly reduced to 50 % by means of an applied current magnetic field. In this constitution, however, since the underlayer is a high-conductivity layer of Cu,  $I_3$  in Fig. 10 shall be large and the current magnetic field,  $H_{cu}$ , to be obtained according to the formula (1-5) shall be small. In other words, the bias point controlling method is to cancel the large  $H_{pin}$  by the small  $H_{cu}$  that is opposite direction to  $H_{pin}$ , which is impossible to attain a good bias point value. It is further known from Table 2 that the increase in the subbing Cu thickness results in further increase in the bias point.

Through our experiments mentioned above, we, the

present inventors have found that the bias point designing is quite difficult in the constitution of U.S.P. No. 5,422,591, and that forming the high-conductivity Cu layer as the underlayer of the comparative case makes the bias point more impracticable.

From the viewpoint of the thermal stability for the MR ratio, the film of USP No. 5,422,591 is not a practical one. As so described in comparative case, the MR ratio in the as-deposited film surely increases owing to the spin filter effect. However, after the thermal treatment for head fabrication, we, the present inventors have found that the MR ratio in the film of the comparative case is greatly reduced as the phenomenon peculiar to ultra-thin free films. This is a serious problem, if high output for high-density recording is intended.

In fact, the MR ratio in the as-deposited film of one example of U.S.P. No. 5,422,591 (this is film (2)) is 1.8 % when the subbing Cu thickness is 1 nanometer. However, after the thermal treatment in our simulation, the MR ratio in the U.S.P. No. 5,422,591 lowered to 0.8 %. As will be mentioned hereunder, the reason for the MR ratio reduction will be essentially because of the antiferromagnetic film of FeMn in U.S.P. No. 5,422,591. Even if the ultra-thin free layer, with which it is difficult to realize high MR, is used in the spin valve film so as to forcedly increase the MR ratio in the film